A Decision-supported Outpatient Practice System

Randolph C. Barrows Jr., MD; Barry A. Allen, PhD; Kenneth C. Smith, PhD;
Vasuraj V. Arni, MS; Eric Sherman, MD
Department of Medical Informatics
Columbia University, New York, NY

We describe a Decision-supported Outpatient Practice (DOP) system developed and now in use at the Columbia-Presbyterian Medical Center. DOP is an automated ambulatory medical record system that integrates in-patient and ambulatory care data, and incorporates active and passive decision support mechanisms, with a view towards improving the quality of primary care. Active decision support occurs in the form of event-driven reminders created within a remote clinical information system with its central data repository and decision support system (DSS). Novel features of DOP include patient specific health maintenance task lists calculated by the remote DSS, uses of a semantically structured controlled medical vocabulary to support clinical results review and provider data entry, and exploitation of an underlying ambulatory data model that provides for an explicit record of evolution of insight regarding patient management. Benefits, challenges, and plans are discussed.

INTRODUCTION

The current health care milieu dictates increased use of ambulatory care services and the need for integration among systems that provide ambulatory, in-hospital, and ancillary information services. Paper medical records will not likely serve this need due to acknowledged weaknesses including poor organization, inaccessibility, incompleteness, and inaccuracies of recorded health data. In addition, paper-based systems are costly to maintain; function poorly for communication, decision support, and ambulatory care effectiveness research[1]; and suboptimally provide for health data security[2]. In response to these limitations, automated ambulatory medical record systems (AAMRSs) have been developed[1] and continue to be an area of ongoing investigation. Reports in these proceedings and elsewhere document efforts to overcome barriers to their use. Recognized barriers include the human-computer interface, the capture of health data in structured and coded formats directly from care providers, limited user-perceived benefits compared to costs and inconveniences of system use, and lack of proven benefits towards decreasing costs and increasing the quality of care[1]. Interfacing and data exchange with central and legacy clinical and administrative systems can also be a significant challenge to AAMRS implementations.

Motivated by a project to demonstrate real-time computer-based quality management in primary care, we have developed a Decision-supported Outpatient Practice (DOP) system. DOP is an AAMRS that integrates in-patient and ambulatory care data, and incorporates active and novel passive decision support mechanisms, in an effort to overcome limitations of previous systems and improve the quality of care. DOP also facilitates direct provider data entry via novel uses of a semantically structured controlled medical vocabulary. These features as well as the general system implementation are described below.

SETTING

CPMC has resources and infrastructure developed partially under a phase III Integrated Advanced Information Management System (IAIMS) grant from the National Library of Medicine[3]. Elements include network cabling and wide area network (WAN) connectivity between clinical, scholarly, research, and administrative sites; networked clinical workstations at (largely) in-patient locations; a clinical information system (CIS) consisting of a central patient data repository, and an event-driven alerting decision support system (DSS) with its knowledge base of medical logic modules (MLMs) written in the Arden Syntax; a semantically-structured controlled medical vocabulary called the Medical Entities Dictionary (MED); a Health Level Seven (HL7) "service access point" (HL7SAP) to communicate with the central repository; and data access/storage modules (DAMs/DSMs) that implement queries and data storage requests at the central repository. The CIS resides on an IBM mainframe computer remotely located from the CPMC campus and linked via T1 lines. Project funding has allowed extension of network connectivity to local and remote ambulatory care areas, and provided for a desktop "486" or Pentium-based PC in over 100 primary care consult/exam rooms.

AMBULATORY DATA MODEL

The DB2 database of the central data repository implements a generic relational model of medical activities[4]. Within this generic relational framework, we have implemented a data model to support a complete computerized ambulatory care record. The model accommodates coded data capture for decision support activities, and provides for an explicit record

0195—4210/96/$5.00

of evolution of insight regarding patient management[5]. Such a record is of clinical utility, provides for improved research capabilities, and serves medical audit concerns.

DATA ACCESS AND STORAGE

When patients are "registered" for an ambulatory visit, subscribing systems receive a broadcast of this billing event. Upon notification, or due to a request from the user interface (DOP), a "data engine" program (Dataengine) running under AIX on an IBM RS/6000 composes HL7 queries to retrieve all available patient-specific data from the central repository. The queries are serially composed and submitted via HL7SAP. Dataengine integrates and stores patient data locally in a machine-independent format optimized for ease of display. An ASCII data "wire" is written as a compressed and encrypted disk file so only authorized system users may read the data. Currently the local transient data model is expunged eight hours after its last use.

Available clinical data includes demographics, laboratory data, pathology reports, imaging and electrographic reports from various departments, operative and procedure reports including pulmonary function tests, discharge summaries, and ambulatory data including vital signs and visit notes. A suite of queries for all data on a single patient generally takes 30 seconds to 2 minutes or more to complete, depending upon the volume of data.

Generally, data gathering is complete and data is locally available to DOP users well before provider access is required, but ad hoc lookups may be subject to an initial delay as data gathering completes. This has been addressed by an algorithm that initially makes available only the most recent instances of each data type. Plans to ameliorate this delay include performance tuning of DAM queries and code, and retention of the transient local data model for prolonged periods (i.e., 1 year after last access) with periodic updates. Current projections plan for 20,000 active patients with a median data file size (compressed) of 250Kb, requiring only 5 Gb.

USER INTERFACE

The user interface program (DOP) is implemented in X Windows and executes on an IBM RS/6000. It is made available to desktop clients via X server software (Reflection X, WRQ, Seattle, WA) that runs under MS Windows. DOP reads the local transient data model built by Dataengine when user access is required, and maintains an in-memory model of all patient data for rapid access.

User interface design is based upon the work practice analysis and ideas of Tang et al.[6,7] The main DOP review screen seeks to supply primary care information needed prior to seeing a patient in the context of

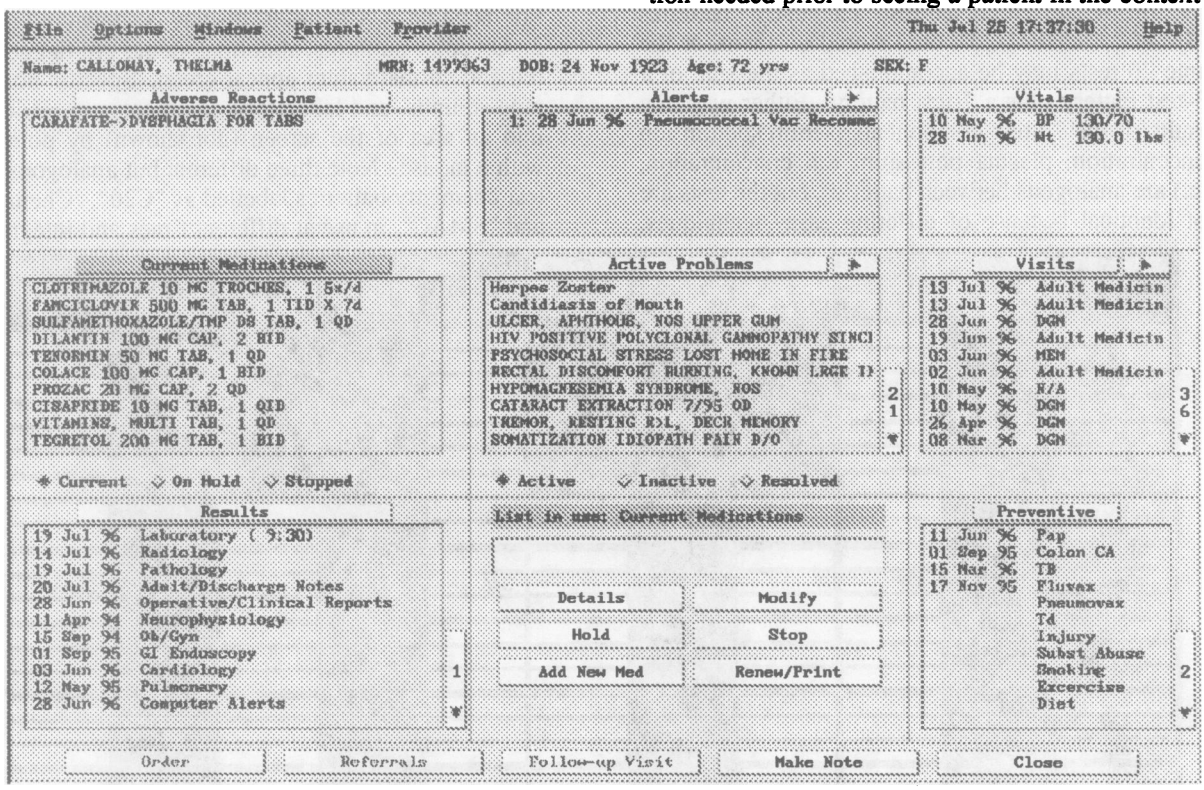

Figure 1. DOP main screen provides an overview of ambulatory patient status.

an ambulatory visit. Ambulatory care is characterized by a relatively high number of short duration patient encounters and frequent unmet information needs. As discerned by ethnographic studies of physicians' work practices, providers first seek to establish a patient's general health status from an overview of active problems, current medications, recent clinical results, health care encounters, and recommended health maintenance interventions. These items along with allergies, recent vital signs, and computer-generated clinical alerts appear on a single screen in DOP [Figure 1]. Detail information, such as the evolution of understanding about a patient problem or a drug therapy (exploiting the ambulatory data model), is available by selecting an item from the pertinent list and selecting "Details" via mouse button click.

VOCABULARY-DRIVEN RESULTS REVIEW

Detail information about clinical results includes longitudinal summary reviews of laboratory data. It is desirable to review data in this fashion to encourage trend detection and discourage redundant test ordering. A challenge arises, however, when instances of analogous or similar, but not identical, test batteries are processed by clinical laboratories and stored as coded data in the central repository. This has been the case at CPMC due to multiple clinical laboratories that update their technology and methodology from time to time. Patients may have, for example, any of 4 different 20-test chemistry batteries ("SMAC", "CHEM-20", etc.) stored on them, or the same 20 tests may be accomplished as the sum of a 13-test battery plus a 7-test battery. Either way, the results of the 20 test components (serum sodium ion concentration, plasma potassium ion concentration, etc.) are analogous between batteries, but the tests are not identical because of differing assay techniques, normal range values, and specimen types. Consequently, each battery and each of its component tests exists as a unique entity in the MED, and analogous results are stored with different codes in the database. Providing a longitudinal summary of laboratory results requires knowledge about analogous batteries and tests, and about which clinical results are meaningfully grouped. One also desires to review *all* available results on selected tests, but usual review mechanisms are "battery oriented", not test oriented. Thus when reviewing past **Lipid Profiles**, one might miss the pertinent **Total Cholesterol** level that occurs as part of a **CHEM-20**, and will typically not see an integrated review of all **Cholesterol** levels.

A clinical vocabulary and data dictionary with semantic attributes and a flexible type-hierarchy, such as the MED[8], provides a solution to this challenge. Analogous or clinically similar test-battery entities are grouped into a container class in the MED. Likewise, each of their component tests are grouped into analogous container classes. Finally, a display entity is defined with attributes that dictate which batteries are displayed and how component tests map onto the display. An advantage of this solution is a layer of indirection that insulates the application program from changes in clinical laboratory operations. When new batteries and tests are added, no changes in application code are necessary to accommodate an integrated display of new laboratory data.

For example, a "Chem-20" display is shown in Figure 2. On color monitors, abnormal values are flagged as red and normal values appear green. Specific normal ranges, units, and laboratory comments are retrieved into an area of the screen (not shown) by pointing with a mouse. Note three different but analogous 20-test chemistry batteries labelled as "C20", "Chem-T", and "SMAC", in use at different times and integrated

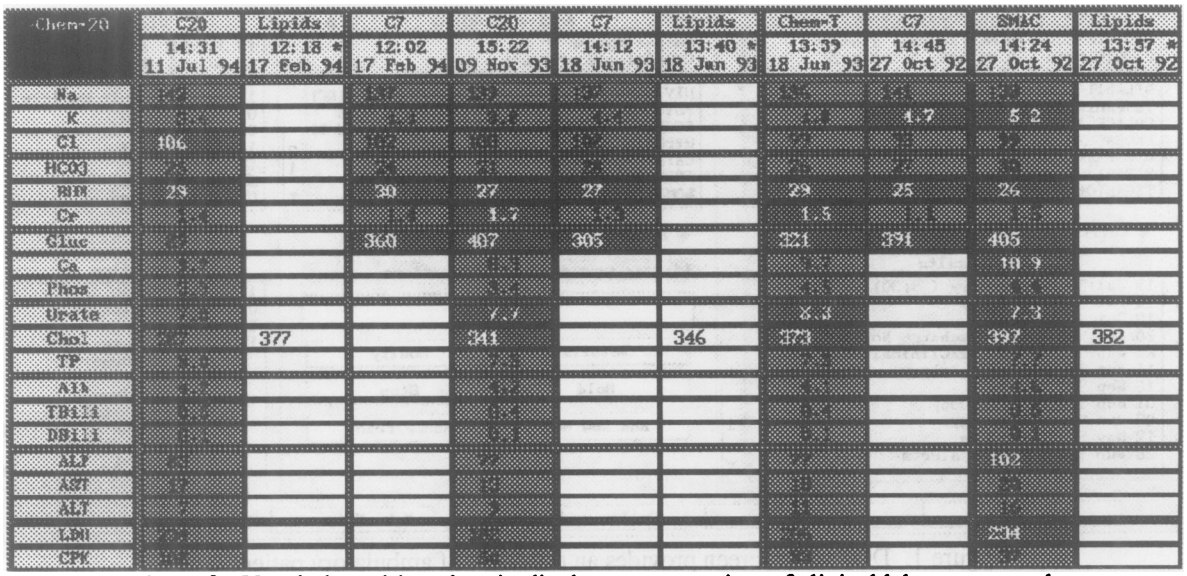

Figure 2. Vocabulary-driven longitudinal summary review of clinical laboratory results.

into the display. Analogous but non-identical test components are mapped to rows such as "Na" and "K". Note also that this display accommodates all elements of a "C7", and displays the "Chol" part of lipid panels. The entire lipid panel is accommodated on another display, and that display also shows "Chol" tests that occur as part of 20-test chemistry batteries.

ACTIVE DECISION SUPPORT

The CPMC decision support system implements a database event monitor[9] and clinical decision rules written in the Arden Syntax for Medical Logic Modules (MLMs)[10]. We have written an MLM that determines recommended health maintenance interventions for patients based upon their age, gender, and clinical problems. The MLM is triggered by a number of clinical events including ambulatory visits, and recommended interventions from the decision support system are stored as coded data and displayed in the user interface under "Preventive" [Figure 1]. Users respond by indicating when patients have received recommended preventive interventions such as counseling, vaccines, and screening tests. We have also composed a suite of MLMs that implement boundary guidelines for a basic package of preventive health recommendations according to the U.S. Preventive Services Task Force[11]. For instance, the mammography MLM, when triggered, determines whether eligible patients have a mammogram report or a user assessment regarding mammography stored in the clinical repository within the past 2 years. If not, an alerting message is stored in the database and is retrieved for display to clinical users when patient data is requested.

INTERFACE TO CONTROLLED MEDICAL VOCABULARY

Integral to the capture of coded ambulatory data in DOP is obligate provider interaction with the MED, which now contains nearly 50,000 medical entities. Each entity is defined with some subset of 150 different attributes that may be literal (string or numeric) or semantic valued (points to another entity in the dictionary). Controlled vocabulary is made available to programs and users via a server-based shared-memory structure with a library interface and a graphical API[12]. Simple lexical searches may produce unwieldy results for naive clinical users, so we utilize application context to apply semantic filters that enhance search specificity[13].

An option exists for graphically navigating the dictionary type-hierarchy from a contextually-appropriate starting point to locate a desired concept. For example, in Figure 3, after a lexical search for "Hepatitis" within the context of choosing a patient problem, a user has selected "Viral Hepatitis" as a starting point for graphical browsing. Note the graph indicates that "Viral Hepatitis" is both a "Hepatitis" and a "Viral Infection". A number of sibling and child (more specific) concepts relative to "Viral Hepatitis" are displayed. A user may now refocus the graph on an area of interest via a mouse click. For instance, clicking on "Hepatitis Delta ..." would reveal the 4 sub-types delta hepatitis "Without ... Active Hepatitis B Disease or Coma."

OTHER FEATURES

Dop entered production use in an academic general internal medicine practice at CPMC during June, 1996. Residents and attendings in this integrated practice are entering coded data, vital signs, and visit notes on a regular basis. DOP prints prescriptions which, along with the increased availability of the electronic data, provides a major incentive for providers to enter their ambulatory patient data. DOP also allows easy composition of ambulatory visit notes. Patient problems, medications, allergies, vital signs, and health maintenance activities are incorporated into the note automatically so typing is minimized. If users choose to create a totally electronic visit record, then no paper copy is necessary per official hospital policy. If users are uncomfortable with typing blocks of text, they may print a "pre-started" visit note, with legible problems and medications, etc., and record other visit details by handwriting, for the paper record. In our setting, however, hospital paper charts are available for less than 60% of ambulatory internal medicine visits (unpublished data), so there exists a general perception of benefit

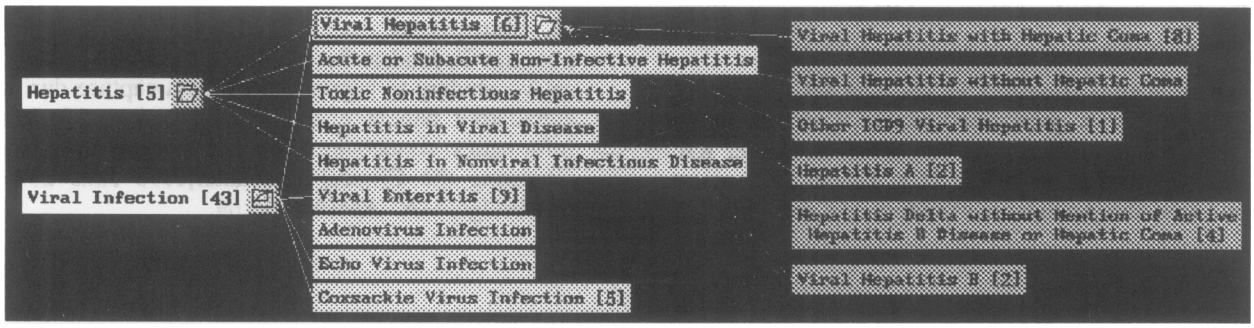

Figure 3. Graphically browsing the dictionary.

and willingness regarding the utilization of electronic records, even among those who don't :-).

Hurdles to use of the system by some residents and attending physicians include general unfamiliarity with a windowing computer interface, and learning-time cost barriers, particularly among individuals who did not already utilize our legacy ambulatory computer-based system. These hurdles are not deemed insurmountable, and a controlled trial has been planned to evaluate the effectiveness of automated clinical reminders in our practice setting.

SUMMARY

DOP integrates in-patient and ambulatory care data, and incorporates active and passive decision support mechanisms with a view towards solving the information needs of ambulatory care providers and improving the quality of care. A particular area of focus is improving compliance with established preventive health recommendations. The system makes use of an ambulatory data model which is able to capture and provide an explicit record of evolution of insight regarding clinical thinking and patient management. The system also makes novel use of a semantically-structured controlled medical vocabulary to enable longitudinal clinical laboratory summaries and the capture of coded ambulatory data directly from providers.

This work is supported by a grant from the New York State Department of Health, and a grant from the John A. Hartford foundation.

References

1. Agency for Health Care Policy and Research, Public Health Service, USDHHS. Automated Data Sources for Ambulatory Care Effectiveness Research (Grady ML, Schwartz HA, editors); May 1993. AHCPR Pub. No. 93-0042.

2. Barrows RC, Clayton PD. Privacy, confidentiality, and electronic medical records. JAMIA, 1996 Mar/Apr; 3(2):139-148.

3. Clayton PD, Sideli RV, Sengupta S. Open architecture and integrated information at Columbia-Presbyterian Medical Center. MD Computing, 1992; 9(5):297-303.

4. Friedman C, Hripcsak G, Johnson SB, Cimino JJ, Clayton PD. A generalized relational scheme for an integrated clinical patient database. In: Miller RA, editor. Proceedings of the 14th Annual Symposium on Computer Applications in Medical Care; 1990 Nov 4-7; Washington, DC. IEEE Computer Society Press, 1990:335-9.

5. Barrows RC, Johnson SB. A data model that captures clinical reasoning about patient problems. In: Gardner RM, editor. Proceedings of the 19th Annual Symposium on Computer Applications in Medical Care; 1995 Oct 28-Nov 1; New Orleans (LA). Hanley & Belfus, Inc., 1995:402-5.

6. Fafchamps D, Young CY, Tang PC. Modelling work practices: input to the design of a physician's workstation. Proceedings of the 15th Annual Symposium on Computer Applications in Medical Care; 1991 Nov 17-20; Washington, DC. McGraw-Hill, Inc.,1991:788-792.

7. Tang PC, Annevelink J, Fafchamps D, Stanton WM, Young CY. Physician's workstations: integrated information management for clinicians. Proceedings of the 15th Annual Symposium on Computer Applications in Medical Care; 1991 Nov 17-20; Washington, DC. McGraw-Hill, Inc.,1991:569-573.

8. Cimino JJ, Clayton PD, Hripcsak G, Johnson SB. Knowledge-based approaches to the maintenance of a large controlled medical terminology. JAMIA, 1994 Jan-Feb; 1(1):35-50.

9. Hripcsak G, Clayton PD, Cimino JJ, Johnson SB, Friedman C. Medical decision support at Columbia-Presbyterian Medical Center. In: Timmers T, Blum BI, editors. Software Engineering in Medical Informatics. Amsterdam: North-Holland, 1991, pp. 471-9.

10. Hripcsak G. Writing Arden Syntax Medical Logic Modules. Computers in Biology & Medicine, 1994 Sep; 24(5):331-63.

11. Report of the U.S. Preventive Services Task Force. Guide to Clinical Preventive Services. 1st edition. Baltimore:Williams & Wilkins, 1989.

12. Barrows RC, Cimino JJ, Clayton PD. Mapping clinically useful terminology to a controlled medical vocabulary. Proceedings of the 18th Symposium for Computer Applications in Medical Care; 1995 Nov 5-9; Washington, DC. Hanley & Belfus, Inc., 1994:211-5.

13. Barrows RC, Allen B, Clayton P, Cimino J, Sherman E, Jenders R. A GUI to a controlled medical vocabulary to support coded data capture during ambulatory patient encounters. American Medical Informatics Association (AMIA) Spring Congress: Capturing the Clinical Encounter;1995 June 25-8; Cambridge, MA. AMIA,1995:69.